PALO ALTO FLOOD BASIN HYDROLOGY

COMMENTS ON CITY OF PALO ALTO'S INDEPENDENT STUDY

OCTOBER 1984

Santa Clara Valley Water District

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SANTA CLARA VALLEY WATER DISTRICT

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OCTOBER 1984

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PREFACE

This report addresses the differences in two studies conducted by the Santa Clara Valley Water District and the City of Palo Alto regarding the extent of needed flood control improvements to the Palo Alto Flood Basin.

The City has questioned the District's hydrologic method and analyses used to determine the extent of needed levee raising at the basin. This report explains and compares the District's hydrologic method and the method used by the City's consultant, Linsley, Kraeger Associates. The report does not compare the two hydraulic analyses of the basin and its operation as there is no present disagreement on this aspect of the problem.

PURPOSE OF THIS REPORT

The report has been prepared in response to the request of the Palo Alto City Council as conveyed to the District in a letter from the City Manager dated June 19, 1984 (Appendix I). The purposes of the report are to:

- Describe the District's hydrologic methods
- Explain how the District's hydrologic methods were applied to the Palo Alto Flood Basin
- Compare the District's methods with the method used by the consultant for the City of Palo Alto, as applied to the Palo Alto Flood Basin.
- Explain why the District chooses not to use the Stanford Watershed Model or other similar techniques.

SUMMARY

Many questions have been asked by the Palo Alto City Council during their deliberation of the District's recommendations for the Palo Alto Flood Basin. The following highlights the major questions and the District's answers as provided in the context of this report.

What is the issue?

The Santa Clara Valley Water District has determined that levee raising is needed at the Palo Alto Flood Basin before upstream flood control work can be done to the basin's tributary channels, Adobe, Barron and Matadero Creeks. The City has expressed concerns about the degree of levee raising required and about possible disruption of the Baylands environment and has challenged the need to raise basin levees based upon the District's hydrology study (that is, the District's estimation of the amount of storm water to be accommodated by the basin). The City retained a consultant, Linsley, Kraeger Associates, to perform an independent hydrologic study which, if adopted, would require less levee raising - and, consequently, less impact to the Baylands - than that proposed by the District.

What is hydrology?

Hydrology is the science that deals with the circulation of water. Flood control hydrology is the science of estimating the magnitude of floods from watersheds and analyzing their frequency of occurrence. Flood waves (hydrographs) are described as having peaks and volumes. Flood control agencies throughout the nation use the 1% peak flow (flood) to design flood control channels, and the 1% flood volume to design flood basins, etc. The 1% flood is that flood having a 1% chance of being equalled or exceeded in any year. The 1% flood has been adopted by the Federal Emergency Management Agency (FEMA), the United States Soil Conservation Service (SCS), the Corps of Engineers and most local flood control agencies as a design standard for flood protection measures.

(Please refer to page 9 for further discussion of hydrology)

What have the two separate studies of the Palo Alto Flood Basin concluded?

The Santa Clara Valley Water District (using three independent hydrologic techniques) has shown that the water surface elevation from the 1% flood can be expected to reach elevation 5.7 feet (National Geodetic Vertical Datum, NGVD) in the Palo Alto flood basin while the City's consultant (using a single technique) believes that the 1% elevation will be no more than 3.1 feet, a difference of 2.6 feet.

How could two separate engineering studies result in two different conclusions?

Studies by the District and the City have used two widely differing methods. The District's methods rely mostly on the analysis of actual streamflow records as the major input rather than rainfall, because streamflows cause flooding. Flood control agencies in California and across the nation use methods similar to those used by the Distict.

The City's consultant has used a method that relies upon rainfall records and attempts to model complex relationships between rainfall and runoff (streamflow). It is used by a few agencies and firms for storm water management studies and for pollution studies, but as yet not for the design of major flood control facilities. The consultant's method is based upon the Stanford Watershed Model (SWM). The method is in the early stage of development as it relates to flood control design applications.

(Please refer to pages 15, 16, 17, and 46)

Palo Alto's consultant has said that its results are more reliable because they used a longer record of rainfall than did the District. Is this a valid point?

It is true that the District used streamflow data recorded between 1952 and 1976 within Santa Clara County and supplemented this with streamflow data starting as early as 1915 from other stations. Palo Alto's consultant utilized rainfall records at Palo Alto that extend back to 1910. They chose to do this apparently without regard to the availability of a wealth of streamflow data. Part of the rainfall data used by the City's consultant are of questionable value because some of the data are from unpublished records, while other data (their simulated hourly values) are derived from recorded daily (instead of hourly) rainfall totals which cannot be used to establish reliable storm intensities for defining peak flows. Their other data are composed of records from different stations without regard to proper timing and other necessary adjustments. Therefore, although they used a longer record of precipitation, the quality of that data, and the way in which the data were utilized, is questionable.

(Please refer to pages 10, 22 and 33 of this report)

Has the District ever used the Stanford Watershed Model?

Yes. In the late 1960's, a local consultant, Carrol Bradberry and Associates was hired by the District to use the Stanford Watershed Model to "simulate" hydrologic data within the District. That simulated data was subsequently found not to be useful for flood control design. An evaluation of all available hydrologic methods has shown that the most reliable results can be obtained by adopting a more direct method - that is a method that relies upon direct statistical analyses of historical streamflow records. Such a method is much more commonly used and accepted, especially in areas such as Santa Clara County which has an adequate stream gaging network both within and outside the County. Such a network provides great quantities of data which can be used in statistical methods.

(Please refer to pages 46, 47 and 48 of this report)

Do other flood control agencies use the (Palo Alto) consultant's method (Stanford Watershed Model) for flood control design?

Of the many agencies polled in California and across the nation, none use the Stanford Watershed Model for flood control design.

(Please refer to page 46)

Do other agencies use the Stanford Watershed Model for anything?

It is used by some agencies for studies which estimate pollutant discharge and, to a limited extent, for some generalized storm drain studies.

(Please refer to page 46)

Does the National Weather Service (NWS) operate a flood warning system based upon the Stanford Watershed Model?

No. However, the NWS does offer a flood warning system that estimates the timing and magnitude of flood flows during storms using the Sacramento 8 Model, a completely different program than the Stanford Watershed Model. "There is very little comparison between Sacramento 8 and the Stanford Watershed Model. The two models are based on different concepts of the hydrologic process." (Larry Ferrall, Deputy Hydrologist-in-Charge and co-author of Sacramento 8, NWS, Sacramento, April, 1984.)

The Sacramento 8 Model can be utilized for certain levels of flood warning because it is interactive — that is, it can be adjusted by human intervention during storms. This is not, however, a method that can readily be used for studying flood control design flows and volumes. "The National Weather Service uses the Sacramento 8 Model for flood forecasting (warning) only, not for flood control design" (Dr. John Schaake, former MIT professor and present Chief of Hydrology Group, NWS, June 20, 1984).

What are the District's main concerns regarding the Palo Alto consultant's hydrologic method in the case of the Palo Alto Flood Basin?

The main concerns are:

1. The Stanford Watershed Model depends on rainfall data rather than streamflow data. Streamflow data are more representative of watershed response than rainfall data.
2. Even though the Stanford Watershed Model may model the hydrologic process within a watershed, the assumption is made that almost all of the

inputs to the model are constant, aside from rainfall. (For example, they assumed that the areawide distribution of rainfall is constant over 73 years of record. This has the effect of dampening - or lowering - any derived design flood volumes).

3. Because of the way historical rainfall and streamflow data were handled, the actual intensity of storms has been smoothed over; hence, the resulting estimates of design runoff volumes produced by this method are too low.

4. The City's consultant did not determine the water surface elevation in the basin that can be expected from the 1% flood from Adobe, Barron and Matadero Creeks. Therefore, it is not clear whether their recommendations would satisfy Federal Emergency Management Agency (FEMA) requirements. (The Consultant determined what they described as the "1% water surface" rather than the water surface from 1% flood flows into the basin).

   (Please refer to page 33)

How does the District's hydrologic method differ from that of Palo Alto's consultant?

As stated above, the District's computer-based method emphasizes the use of actual streamflow records and, to a lesser extent, rainfall records. The District utilized three independent techniques to cross-check the results. In the case of the Palo Alto Flood Basin, the streamflow records of the stream gage on Matadero Creek were analyzed statistically and initial results were obtained. As a verification, the records from stream gages within and outside the County were analyzed using techniques that permit a "regional" analysis to be applied to specific watersheds - in this case, the watersheds of Adobe, Barron and Matadero Creeks. The resultant flows and runoff volumes from the application of this analysis of regional data to the Matadero Creek watershed were compared with the initial results of the Matadero Creek recorded streamflow data. Finally, flows and volumes were analyzed using a rainfall/runoff model as an independent check on the prior two analyses. Each of these steps include separate consideration of developed (urban) areas. For urban areas, the rainfall runoff model is used to analyze runoff from both impervious (paved) and pervious (unpaved) parts of the watershed. Results from these three independent analyses at the gage location on Matadero Creek were found to be nearly equal — a good check on the applicability of regional techniques to ungaged and rural locations.

In contrast, the Palo Alto consultant's analysis is based on a singular method which attempts to model the historical and continuous relationship of rainfall and runoff. The model also "simulates" continuous runoff data wherever needed. Most of the information utilized in the Stanford Watershed Model is variable in nature (rainfall distribution, storage factors, evaporation, infiltration, etc.) but, except for rainfall, are considered constant in the analysis. This assumption has a smoothing effect which dampens (lowers) the extreme events and results in an underestimation of design flood values.

(Please refer to page 22)

Doesn't the District's hydrologic method rely on simple text book formulas and tables?

No. The District's hydrologic analyses of the Palo Alto Flood Basin includes complex hydrologic and statistical computer models. The intensive use of the District's data base together with these computer models, permitted the analysis and reanalysis of great amounts of data for many different design conditions. These are available for the public's inspection at anytime.

Is hydrology an exact science?

No. It has many practical applications, such as flood control which deals with natural processes that are random and ever-changing. Therefore, it is dependent on the laws of probability for analysis of past data and projection of future chances of occurrence.

The consultant has said that the District compounded actual probabilities and, as a result, has designed the flood basin for the 400-year flood rather than the 100-year flood. Is this true?

No. There is no hydrologic method that is immune to the possibility of compounding probabilities; however, all responsible hydrologists acknowledge that possibility and are careful to avoid producing results which have, in fact, a greater or lesser chance of occurring than 1% each year. The District has demonstrated that any such compounding in it's method is negligible. The assertion by the consultant that the District's 100-year flood is actually a 400-year flood is unfounded.

(Please refer to page 19)

Are there ways to verify the results of either study?

Yes, there are two major observations that lend credence to the District's results:

1. The volume of storm water runoff that the consultant advises would produce a 1% water surface elevation in the basin (3,500 acre-feet) is extremely small when compared with the volume of runoff from the historical 1% storm of 1911.
2. The elevation of the 1% - or 100-year - water surface as recommended by the consultant (elevation 3.1) was nearly met during the January 1983 storm (elevation 3.0), a 20-year flood as determined by the United States Geological Survey (USGS). Therefore, by observation, the elevation of 3.1 appears to be too low as an estimate of the 1% water surfce in the basin.
(Please refer to page 43)

Before the City contracted for the independent study of the flood basin, one City Council Member questioned the District's derived rainfall for the year 1943, saying the District's results were too high. Does the consultant's study agree or disagree with the District's results for that year?

The consultant's study supports the District's finding that, given all available data, 1943 was a very wet rainfall year in Palo Alto.

Is it true that the District does not have the resources to evaluate new hydrologic methods, and, therefore, is stuck with an outmoded system?

No. As described in this report, the District, along with several other flood control agencies, has evaluated the Stanford Watershed Model and other techniques and has chosen not to use them. In fact, this report is an evaluation of the Stanford Watershed Model and its application to the Palo Alto Flood Basin. The District's hydrologic methods are considered to be state-of-the-art.

(Please refer to pages 17, 46 and following)

What is recommended now?

It is recommended that the District be permitted to proceed with the levee construction proposed for the Palo Alto Flood Basin so that the orderly accomplishment of critically needed upstream channel improvements is not delayed further.

BACKGROUND

To better understand the reliability of the District's hydrologic method as it compares to other methods, some background information is offered.

Hydrology

Hydrology is concerned with the study of the natural water cycle that begins with evaporation of water from the oceans and other bodies of water and continues with the formation of clouds, precipitation (rainfall) and then the complex distribution of that rainfall through evaporation, transpiration through plants and their leaves, infiltration into the ground, runoff into streams and major creeks and channels to the oceans where the description of the cycle began. Actually, the hydrologic cycle is much more complicated than this simplified characterization and is the target of a great deal of research and debate. An understanding of the hydrologic cycle must include consideration of the timing of various hydrologic events (lag time between precipitation stations, lag time between storm intensities and their corresponding runoff, etc.).

Flood control hydrology deals with one part of the larger hydrologic cycle — the estimation of flood flows and, more specifically, the estimation of the frequency with which a peak flow and volume of runoff of a given magnitude can be expected to be equalled or exceeded in any year. The aim of flood control hydrology is to improve the statistics — or frequency projections — of floods that could be generated from a given watershed. For example, to design a flood control channel, engineers need to know the peak flow; that is, the maximum rate of runoff in cubic feet per second (abbreviated cfs) that could, on the average, be expected to be equalled or exceeded once in 100 years (said to have a 1% chance of being equalled or exceeded in any one year). Likewise, maximum volumes of rainfall runoff (expressed in acre-feet, abbreviated ac-ft; or in cfs-24 hours) and frequency of occurrence are desired for other flood control facility design problems, such as for reservoirs, sediment facilities and flood basins.

Although peak flow and volume of runoff can be analyzed for any frequency of occurrence (say two-years, five-years, ten-years, twenty-years, etc., or 50%, 20%, 10% and 5% probabilities), the nationwide standard for flood control design was chosen — based on economics — to be the 100-year, or 1% flood.

A limited number of hydrologists assert that peak flows and maximum volumes are not related, that these are independent from each other. For storms in California, there is no question that peak flows are related to maximum volumes. In California, floods occur as a result of intense storms (storms that are usually cyclonic with large fronts). Therefore, we define the 1% flood to be that flood event having a 1% peak and a 1% volume. The question of compounding of probabilities - asserted by some - is discussed later.

The Importance of Good Data

All hydrologic methods rely upon historical data. Streamflow records and rainfall records are essential to any analysis of floods and their frequency of occurrence. Depending on many factors, historical streamflow data at a certain location represent the actual response of the watershed to rainfall activity. Since our interest is in flooding, records of maximum annual streamflows are of more importance to the District than rainfall data.

"It is recommended that rainfall data be given a secondary role . . . in Santa Clara County. Runoff data for about 40 stream gaging stations in the county and around it will produce much more reliable information on floods than the synthesis of precipitation data could yield". (Yevjevich and Simon, 1967, see Bibliography Ref. #1)

Inherent Errors

All historical records have inherent errors that must be dealt with during hydrologic studies:

- Normal Errors are those that exist because of the variability of natural events. All hydrologic methods are subject to these errors.

- Sampling Errors exist because of the deficiencies that result from trying to represent a large amount of data with only a limited sample. All hydrologic methods deal with this type of error.
- Man-made Errors come about because of the inadequacies of certain techniques in handling historical data or in creating data. One such technique which can bias its results is to "simulate" streamflow data by attempting to model the relationship between rainfall and runoff. Such synthetic data are particularly subject to biases that can render the results useless, especially in the case of extreme (flood causing) events.

In relying upon historical records of streamflow and precipitation, great care is taken to ensure the quality of those historical data. While there may be many private, unpublished records kept by individuals, these cannot be used without further assurances that the data were collected in a manner consistent with standards of scientific data collection.

Data published by responsible data collection agencies are usually collected by qualified individuals and, by publication, are subject to further scrutiny by the professional community. It is safer for hydrologists to use such data rather than data obtained from private collectors. The State of California Department of Water Resources (DWR) and the United States Geological Survey (USGS) publish precipitation and streamflow records. The Santa Clara Valley Water District is a contributing agency in these data collection publishing programs.

Gaged Watersheds

Many streams in Santa Clara County have recording stream gages at various locations. Also, a network of over 100 precipitation stations in Santa Clara County automatically record rainfall and provide a long, historical record. Many other streamflow and precipitation stations outside of Santa Clara County — but within the immediate hydrometeorologic (weather) area — complement the District's in-county data network.

Ungaged Watersheds

Many streams and watersheds do not have historical streamflow records. In order to have hydrological data that can be used for flood control design in these ungaged watersheds, some method must be used to estimate peak flows and volumes without benefit of data specific to the watershed. This problem must be addressed regardless of which of the several hydrologic methods is used (a discussion of the various hydrologic methods follows). Nor do all streams and watersheds with precipitation gages and/or stream gages have records that are entirely continuous over the life of the gage. Various circumstances occur during the life of hydrologic gaging devices that can interrupt the data collection process. Such periods can last for hours, days, weeks or even months.

Synthetic Data

To enhance historical streamflow records, that is, to develop synthetic data, hydrologic methods use some form of mathematical or computer technique. The District uses statistical and other mathematical (stochastic) techniques for "filling in" missing data, or for extending short records of data, on gaged streams and watersheds using historical streamflow records of adjoining streams and watersheds. This "filling in" process permits longer and more continuous records to be made available without sacrificing the statistical quality of the data. The filling-in process uses "stochastic" techniques and these yield data that statisticians consider "random, unbiased and homogeneous and with a known standard error of estimate" — qualities that permit further rigorous statistical analyses of the combined data.

Some hydrologists use computer techniques to "simulate" missing streamflow data using rainfall data. Rather than using information from adjoining streamflow stations, the process of "simulating" data attempts to model the continuous and, hence, extremely complex relationship between rainfall and runoff. In such models, many human judgement factors enter into the process. For example, some natural processes, such as the area-wide distribution of rainfall, are quite variable over a period of time; however, for simulation, this is inappropriately assumed to be constant. Nonetheless, simulation models such as the Stanford Watershed Model are most sensitive to rainfall. The results of such modeling can therefore be biased because of the many assumptions that are needed, such as the assumption of constant rainfall distribution, discussed later.

Hydrologic Methods

As there is more than one opinion on the "best" way to handle the problems of incomplete historical records and ungaged watersheds, so there is also more than one opinion on the "best" hydrologic method to estimate runoff peaks and volumes. In fact, some methods are adequate for some engineering applications but not for others.

If there is a consensus at all, it is that for gaged watersheds — that is, for watersheds that have long records of streamflow — there is no better method for deriving design peak flows and design volumes than by the statistical analysis of the historical record — checked if possible against the statistical data from any nearby watershed — and further checked against statistical data for the general region applied to the particular watershed. This is standard practise for the Santa Clara Valley Water District and, with some variation, for the majority of flood control agencies.

However, since most watersheds are not adequately gaged, or are not gaged at all, different points of view among hydrologists arise with regard to analysis of ungaged watersheds.

At the turn of the century, hydrologists began using simple statistical and mathematical tools (such as the rational formula described below, and straight-line projections). As more recorded data become available, scientists and mathematicians became more involved in seeking the best use of the data and quickly many new techniques evolved (various frequency distributions, different interpretations of rainfall and runoff relationships and the movement of resultant flood waves over land). As a result, hydrologists across the nation started using these techniques, each based on his background. This generated inconsistent results, and controversies started. In the late

1960's and early 1970's, the federal government recognized the problem of inconsistent interpretation of hydrologic events and decided to adopt a standard hydrologic method. This was needed for the administration of the National Flood Insurance Program which was in its final stages of nationwide adoption.

The result of the federal efforts in arriving at a national consensus on hydrologic method was the publication of a unifying document — Bulletin #17, Guidelines for Determining Flood Flow Frequency — by the President's Water Resources Council (WRC). Most hydrologists accepted the document and its recommendations.

In the 1970's, the National Flood Insurance Progam was fully implemented. The WRC Bulletin #17 in combination with the Corps of Engineers unit hydrograph technique (described later in this report) were found to have a unifying effect and were, therefore, used by the Flood Insurance Administration for their flood mapping program.

As the National Flood Insurance Program applied the above-described techniques, most flood control agencies adopted these same hydrologic methods for estimating peak flows and runoff volumes. The Santa Clara Valley Water District was the foremost user of those techniques and improved upon them by use of stochastic methods for augmenting the relatively short historical stream gage record at some of the District's stations.

There are several approaches to hydrology in use today by flood control and storm drainage agencies and design firms:

Empirical Method ("Rational Formula")

This is a method for estimating peak runoff and is only suitable for watersheds of extremely small size — perhaps several acres of uniform surface, such as paved parking lots or city streets. It is no longer applied realistically to large, complex watersheds that have rural as well as urban characteristics.

Statistical (Stochastic) Method

This method involves the statistical analysis of historical streamflow and rainfall data (runoff peaks and volumes). As with other methods, the desired results are reliable estimates of 1% (100-year) peak flows and the associated volume of runoff. The backbone of this hydrologic method is the comprehensive statistical analysis of historic streamflow data. This has the advantage over deterministic methods (continuous simulation described below) of avoiding the ambitious task of modeling the continuous relationship between rainfall and runoff. This method includes nationally recommended mathematical techniques to project the historical record. Missing historical data are estimated using stochastic procedures (described above). Final estimates of design peak flows and volumes can, therefore, be analyzed by standard statistical procedures to determine how well they fit with the historical record. In other words, the standard error of estimate of the results can be determined, rather than relying upon just a visual inspection of graphical fit and rather than relying upon the individual hydrologist's judgment of reasonable results as is the case with the below-described simulation techniques.

Deterministic Methods (Continous Modeling)

Deterministic hydrologic methods attempt to model the continuous and complex relationship between rainfall and runoff. One such deterministic program is the Stanford Watershed Model (SWM) developed in the early 1960's. Continuous modeling is proving useful for analyses of pollutant discharge volumes and, to a limited extent, for flood warning systems. However, to date, it appears that SWM does not lend itself to flood control design, for reasons that will be explained.

The idea of continuous modeling is to describe the continuous long term rainfall-runoff relationship using mathematical formulas and functions that try to account for all rainfall once it lands on the surface of the watershed until it passes through the maze of complex paths that water can take after that time. Through an accounting procedure, estimates are made of the runoff that makes its way to the major flood carrying watercourses. The computer model is "calibrated" against a small part of the available historical data for the watershed. If the watershed has no data, then the model is calibrated against the nearest available historical data from some adjoining watershed. The calibrated model is used to generate "simulated" runoff data for periods longer than the period of calibration.

The District's method described below results in the description of a single flood wave with a specific peak flow, volume, shape and frequency of occurrence. Continuous simulation, however, results in the generation of a continuous time-series of peaks, volumes, etc. Statistical analyses of such continuous series would generate design values (peaks, volumes, water surface elevations, etc.), but without a common denominator that relates these design values to each other. In simulation, it is claimed that design flood volumes do not coincide with design flood peaks, and that the total design flood does not have the same probability as that of peaks and volumes regardless of the magnitude and intensity of the storm.

Continuous models are made to manage large quantities of input rainfall data to "perform deterministic simulation of a variety of aquatic processes" (R. K. Linsley). As a result, deterministic data -- or data that could be reproduced given the same input values — are obtained and are treated as purely random events. It is not clear how much randomness is left in this type of data. Also, it is not clear whether the contemporary laws of statistics apply to such results and, if they do, under what conditions and limitations.

THE DISTRICT'S HYDROLOGIC METHOD

The District's hydrologic method has evolved over many years into a procedure that has achieved the endorsement of nationally and internationally respected hydrologists. It is a statistical method similar to that in use by the majority of flood control agencies nationwide. A panel of nationally recognized hydrologists reviewed the District's method in 1976 and recommended that it be disseminated to other flood control agencies for possible adoption as a national standard.*

The method relies primarily upon historical local as well as regional streamflow data and secondarily upon rainfall data. Santa Clara County is fortunate in having many years of streamflow and rainfall data collected at over one hundred gages under a highly competent data collection program. In addition to the District-maintained hydrologic gage network, there are several gaging stations owned and operated by the United States Geological Survey (USGS), and others.

"The secondary role of precipitation means only that the rainfall data, with its more accurate properties (say annual or seasonal values) should be used for estimation of parameters of flood frequency distributions on ungaged watersheds". (Yevjevich and Simon, 1967)

With the above as background, the following is a general description of the District's hydrologic method. A more technical description of the method is available from the District upon request.

Three Cross-Checking Techniques

The District uses a statistical method as described in the previous section on general methods. Rather than relying on a single statistical analysis, the District utilizes three independent techniques that derive results (design peak flows and maximum volumes) that can be compared. Those three independent techniques are:

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*The panel, and their affiliations in 1976, were: Professor Leo R. Beard, University of Texas; David R. Dowdy, U. S. Geological Survey; Professor Neil S. Grigg, Colorado State University; Professor L. Douglas James, Georgia Institue of Technology; Professor V. Yevjevich, Colorado State University.

1. A statistical analysis of historical stream gage records in the watershed of the facility being designed. The results of this analysis are:

   1% peak flow$_{(1)}$

   1% runoff volume $_{(1)}$

2. An analysis of the rainfall/runoff relationship for the facility watershed (unit hydrograph analysis). The results of this analysis are:

   1% peak flow $_{(2)}$

   1% runoff volume $_{(2)}$

3. An analysis of historical streamgage records of streams in the surrounding area and applied to the watershed in question. The results of this analysis are:

   1% peak flows $_{(3)}$

   1% runoff volume $_{(3)}$

The results of the three independent analyses are compared. In fact, the three sets of results can each be given a numerical weighing factor equal to the calculated standard error of estimate, and the finally selected 1% peak flow and 1% volume can, if appropriate, be computed as the weighted average of each of the three results. In some cases the use of a weighted average is not recommended, and rather, one of the three sets of results might be selected for design.

It should be noted that the District's hydrologic method could accommodate a fourth, fifth, sixth, etc. technique in addition to the present three if the additional techniques were to be statistical in nature - that is, if they were each to have a computable standard error of estimate as normally considerd by statisticians. To date, there are no other such techniques beyond those used by the District.

The District's three techniques are shown diagramatically in Appendix II.

Compounding Probabilities

As previously explained, flood control agencies usually design and construct flood control measures to contain the 1% (100-year) flood. Floods can be grouped according to any frequency of occurrence - annual floods, 10-year floods, 20-year floods, 50-year, 100-year, 200-year, 300-year, 1000-year, etc. The 100-year, 1% flood is the common standard that has been accepted for design of flood control facilities. Hydrologists, when they produce estimates of floods are careful that their results actually do have a 1% chance of happening in any year, otherwise the accepted 1% standard may not be achieved. Probabilities of the individual components of floods must be considered so that the end product has a probability of 1%.

Since all hydrologic methods deal with the statistics of flood events, there is always the possibility of inadvertent compounding of probabilities. This is a subject that hydrologists seem to like to bring up when confronted with differences of opinion — especially when the disagreeing parties subscribe to different hydrologic schools (the "stochastic school" versus the "deterministic school", for example). If a hydrologist considers that the probability of occurrence of each of two assumably unrelated factors — such as peak flows and volumes — is one in one hundred (a .01, or 1% chance of each of them occurring), then actually he may have recommended a design flood that has a probability of occurrence of one in ten thousand (.01 multiplied by .01), rather than one in one hundred.

However, if two events are dependent — that is, two phenomena of nature whose individual behaviors are directly related to each other — then, there is no compounding of probabilities, especially when statistical analysis shows the cross correlation between the two events to be very high.

The criterion in these cases is that if the correlation coefficient between peaks and volumes is less than 0.9, then it may be said that their coincidence is less probable and some compounding of probabilities is likely. For Matadero Creek, the computed correlation coefficient between peaks and volumes is 0.942 for the recorded data alone and 0.964 for recorded data combined with derived (reconstituted) data. Therefore, there is no question that peaks and volumes are highly correlated and that the compounding of probabilities in the resultant flood is not significant.* The combination of the probability of peaks and volumes, can safely be assumed to be equal to the probability of the resultant flood. This is because floods are caused by extreme storm events with periods of intense rainfall. Such storms are frequent in this geographical area. Intense storms with small volumes of runoff are usually characteristic of arid (desert) areas and not Santa Clara County.

> "Because the individual peaks and volumes are highly correlated, the effect of considering joint probability may change the resultant probability very little". (1976 Panel Report, page 35, Bibliography Reference #2.)

Because the District's computed cross correlations are in fact less than 1, it is understood that some extremely small amount of compounding of probabilities could occur. For that matter, no hydrologic method used today is immune to the possibility of compounding of probabilities. This is especially the case with methods that attempt to transform rainfall records to runoff records at various locations by assuming that the coincidence of timing of rainfall and all other parameters is extremely probable.

In fact, the very small amount of compounding of probability in the District's method is further reduced by using peak flows to design flood control channels, and flood volumes to design storage facilities, but never peaks and volumes together. In the case of small storage facilities such as the Palo Alto Flood Basin, the water surface elevation is primarily determined by the volume of the inflow. Any adjustment to the water surface elevation due to consideration of instantaneous peak events is negligible.

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* Linsley, Kraeger Associates' simulated peaks and volumes have a computed correlation coefficient of 0.56, which is an observation that casts doubt on the credibility of simulation techniques and the application of the Stanford Watershed Model to flood control design.

Because of the reasons described above -- that is, the high correlation between peak flow and maximum volume and the fact that there is no need to combine peak flows and maximum volumes to design water structures -- the possibility of compounding probabilities in the District's method is negligible.

COMPARISON OF THE DISTRICT'S PALO ALTO FLOOD BASIN ANALYSIS WITH THAT OF LINSLEY, KRAEGER ASSOCIATES

The District's Analyses

The District has calculated 1%, or 100-year, peak flows and their related runoff volumes for the watersheds of Adobe Creek, Matadero Creek and Barron Creek and determined the corresponding water surface elevation in the Palo Alto Flood Basin, the common outfall for these three creeks. The results of that study are documented in the District's 1978 report Hydrology Documentation for the Northwest Flood Control Zone. That report, and several others available at the District office, provide more detailed information.

Of those three streams that flow into the Palo Alto flood basin, Matadero Creek is the only gaged creek with an historical record of streamflows and volumes. At the gage location near El Camino Real, design peak flows and corresponding volumes were calculated using the three separate techniques described previously. The results of those analyses are described as follows:

1. Statistical Analysis of the Matadero Creek Stream Gage Records

Analyses of the streamflow data at the Matadero Creek gage are shown on the following graphs. Figures 1 and 2 show how the actual historical and derived (stochastically reconstituted) peak flows and historical and reconstructed volumes (dotted points) rank with respect to frequency of occurrence. The solid lines through the data points in the two graphs have been plotted using the recommended technique of the United States Water Resources Council, 1976. In Figure 1, the broken heavy line shows the design condition and reflects the effects of urbanization which can, because of the proliferation of paving, roof tops and other impervious surfaces, act to increase runoff. That effect is more pronounced for frequent flood events (left end of the graph) and less pronounced for less frequent flood events (right end of the graph). It should be noted that Palo Alto's consultant, Linsley, Kraeger's, peak streamflow values (shown on

Figure 1 and obtained from Linsley, Kraeger Associates' Figure 10) are higher than those projected by the Santa Clara Valley Water District.

Figure 2 shows the dramatic differences that can result if the maximum 24-hour volumes (appropriate for design) are plotted against the maximum daily (calendar day) volumes (inappropriate for design). The District studies utilize 24-hour volumes.

Figure 3 shows the design 24-hour volume (heavy broken line) compared to the historical record. Notice the effect that urbanization has on increasing runoff volumes as shown by the line labeled "urbanization".

Figure 4 shows the results of Linsley, Kraeger's observed and simulated daily volumes compared to the 24-hour runoff volumes obtained from the District's study and compared to historical, recorded volumes. Linsley, Kraeger's volumes are notably lower than historical data. More discussion about these graphs will follow.

The District's analysis of the Matadero Creek stream gage records gives the following estimate of the 1% peak flow and corresponding volume (Figures 1 and 2):

Peak Flow:	2310 cfs (the District's 1978 Northwest Zone report inadvertently reports this as 2170 cfs due to a typographical error).
Volume:	Daily volume (calendar day) = 560 cfs-days (which equates to 1,108 acre-feet of volume or about 2.8 inches of excess rainfall). 24-hour volume = 710 cfs-24 hours (which equates to 1,405 acre-feet of volume or about 3.7 inches of excess rainfall).

2. Rainfall/Runoff Analysis

The second independent analysis by the District used rainfall records of precipitation gages within the area. Independent estimates of peak flows and volumes were made on Matadero Creek at the gage location near El Camino Real using the unit hydrograph technique (Figures 1 and 3).

MATADERO CREEK STREAM GAGE
Near El Camino Real
PEAK FLOWS

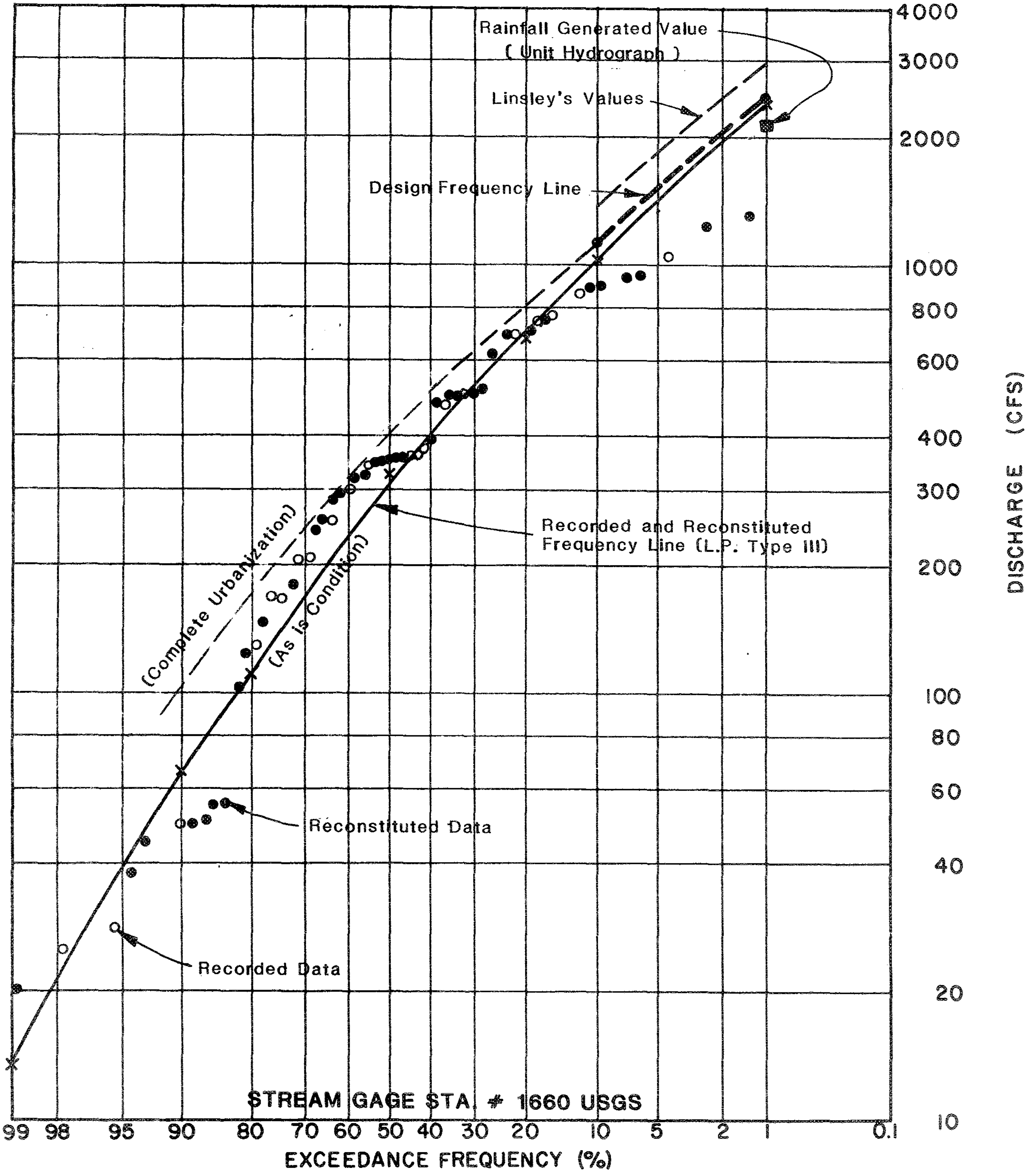


FIGURE 1

MATADERO CREEK STREAM GAGE
Near El Camino Real

(Comparison Of Daily Vs. 24-Hr Volume)

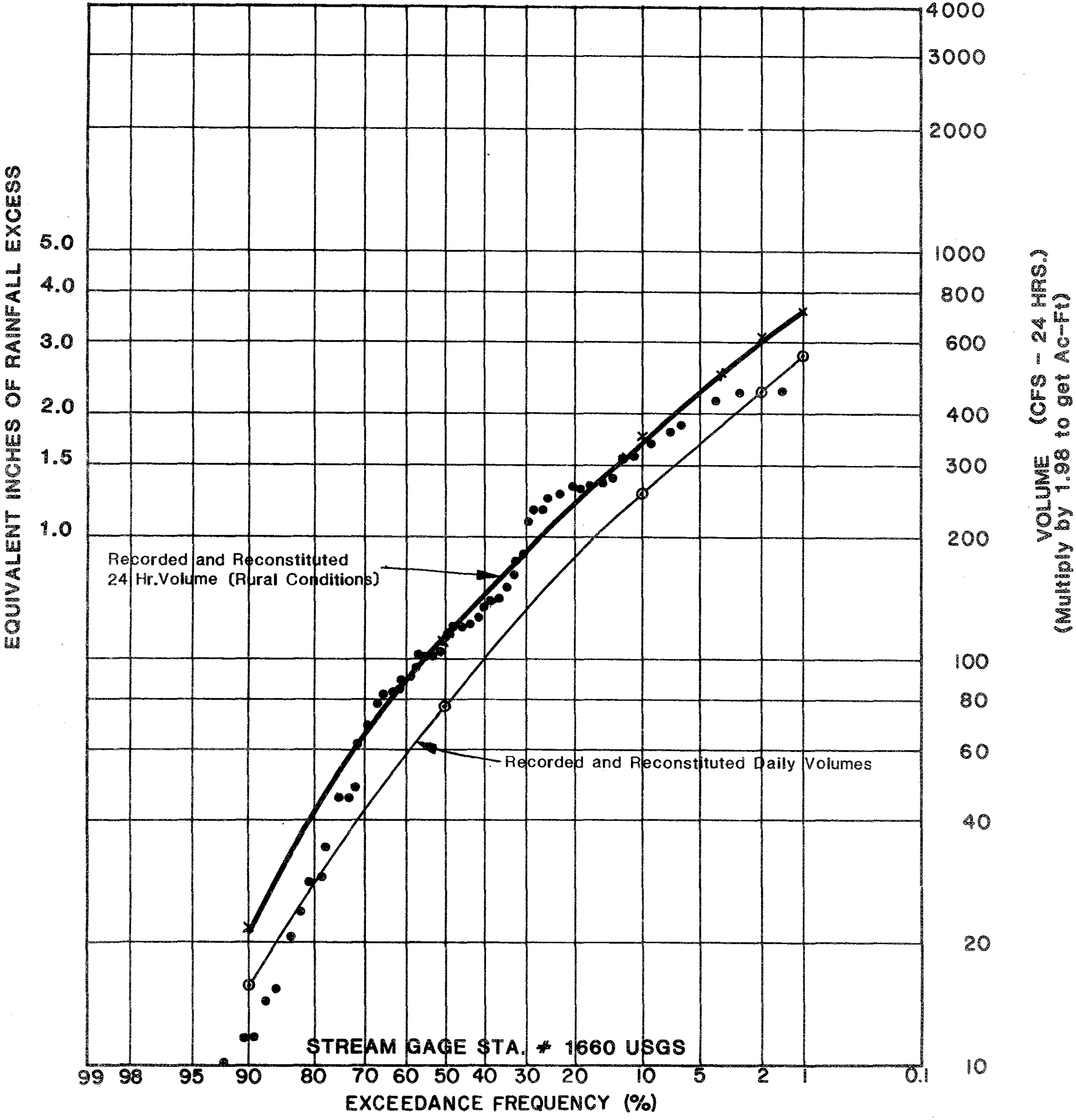


FIGURE 2

MATADERO CREEK STREAM GAGE
Near El Camino Real

(Design Volumes)

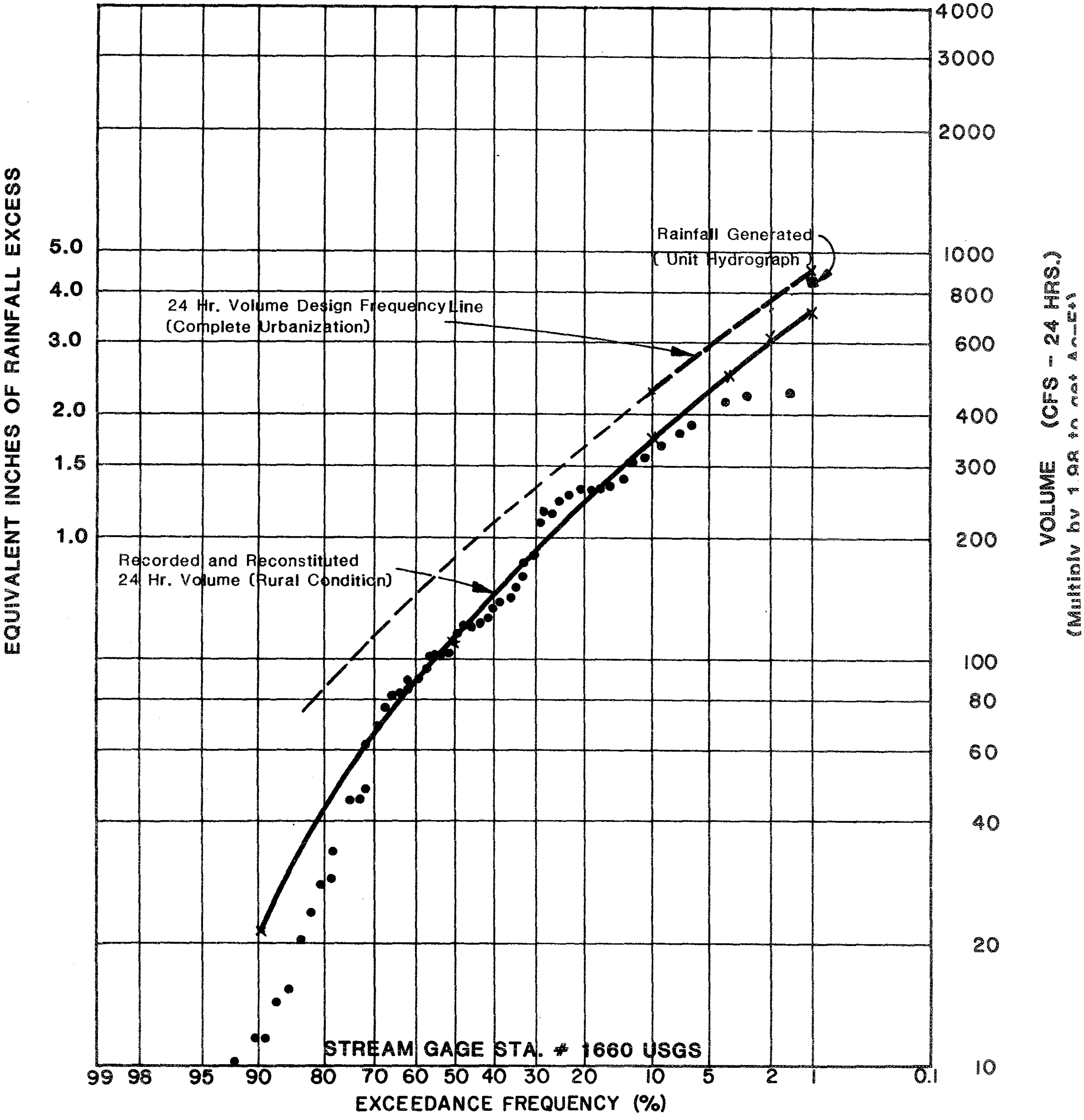


FIGURE 3

MATADERO CREEK STREAM GAGE
Near El Camino Real

(Comparison Of 24-Hr Volumes Vs. LKA's Results)

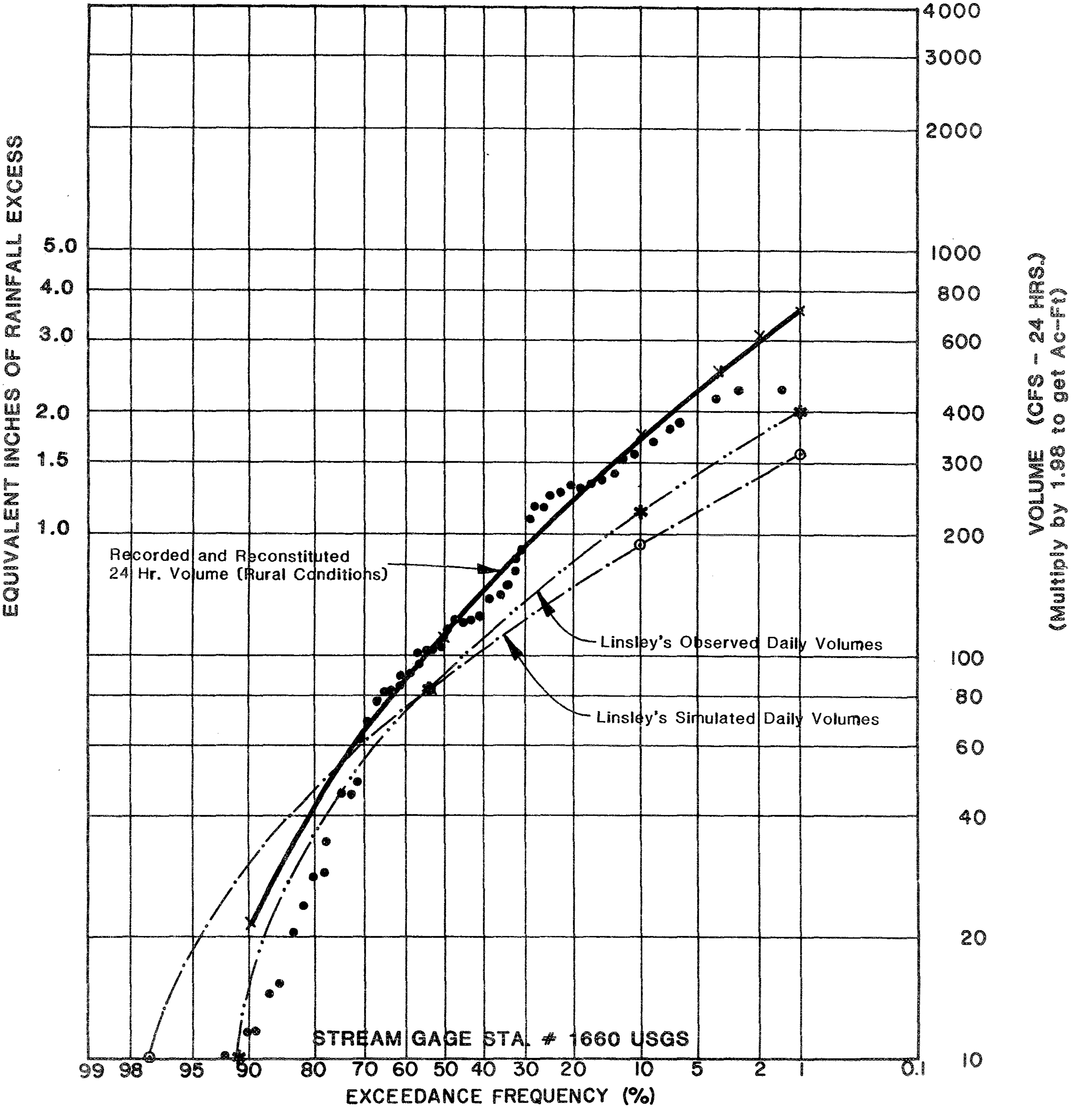


FIGURE 4

The unit hydrograph is somewhat similar -- at least in intent -- to the deterministic modeling approach described earlier in this report. That is, it relates rainfall data from single storms (as opposed to continuous modeling) to their corresponding streamflow data to produce a "unit hydrograph" — a graph showing the direct rainfall runoff equivalent to one-inch of excess rainfall over the basin. The technique is useful for estimating runoff for any known amount of rainfall.

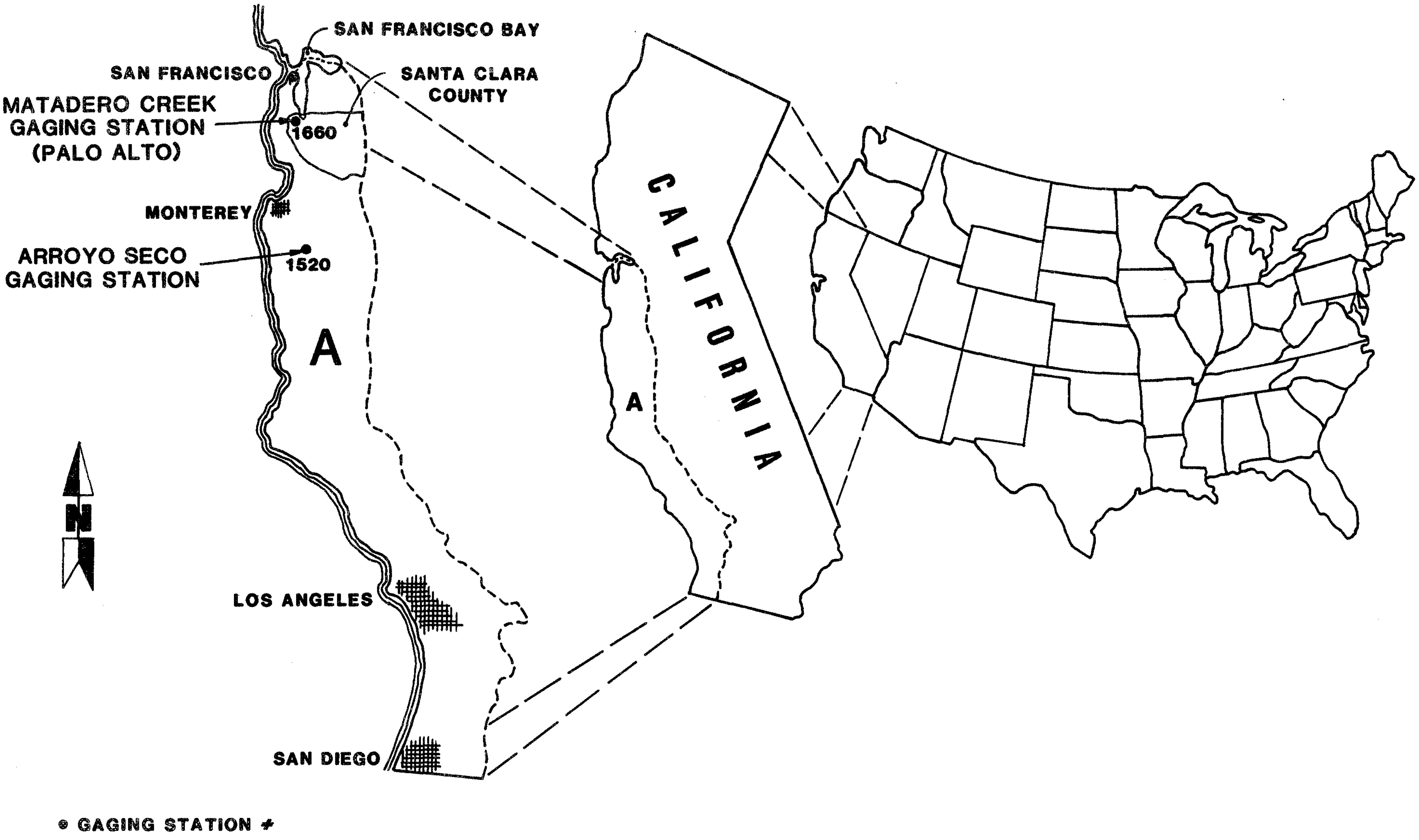
The results of the unit hydrograph analysis for the 1% flood on Matadero Creek are shown on Figures 1 and 3 as points on the frequency lines. The peak and volume so determined are:

Peak Flow:	2091 cfs
Volume:	24-hour volume = 909 cfs-24 hours (which is equivalent to 1,800 acre-feet or about 4.5 inches of excess rainfall).

3. Regional Flood Frequency Analysis

The third comparison technique used by the District is an analysis of the historical streamflow data at the Matadero Creek streamgage compared to data from the immediate hydrometeorological region - that is, the area encompassing Santa Clara County and some surrounding areas which are considered subject to similar storm patterns. This regional analysis permits comparison of the Matadero Creek streamflow record with the streamflow records of gages representing most watersheds in the region. Some 30 such stations were compared for this regional analysis.

One streamflow station in the region with a very long record is on Arroyo Seco Creek, a tributary of the Salinas River south of Salinas. This station has over 100 years of good record and the information in that record is considered to be the most valuable information in any hydrologic study of the region. The Arroyo Seco station is considered by the United States Geological Survey (USGS) and the United States Corps of Engineers (Corps) to be within the same hydrometeorologic region (Region A) as other stations in Santa Clara County, as shown on Figure 5, and was therefore analyzed along with approximately 29 other stations.



MAP OF PACIFIC SLOPE BASINS IN CALIFORNIA SHOWING GAGING STATIONS AND FLOOD FREQUENCY REGION A

FIGURE 5

The results of this regional analysis are two sets of mathematical equations. One relates the statistics of the peak flows to the mean annual precipitation, watershed area, slope and length of creeks, etc. The other set relates the statistics of the runoff volumes (24-hour, 1-day, 2-day and 3-day) to those same watershed characteristics. The District's regional equations are updated as more years of hydrologic data are gathered (every ten years). The equations are currently listed in the District's 1976 report, Development of Regional Regression Equations. The report is available from the District upon request.

With respect to the Matadero Creek stream gage, the results of the regional flood frequency analysis are as follows (refer to Figure 1 for peak flows and Figure 3 for volumes):

Peak Flow:	2369 cfs
Volume:	24-hour volume = 912 cfs-24 hours which is equivalent to 1,800 acre-feet or 4.5 inches of excess rainfall. (At the Palo Alto Flood Basin, 4.5 inches of excess rainfall volume is equivalent to 6,600 acre-feet from the three contributing watersheds.)

The 4.5 inches of excess rainfall noted above is not a unique or remote event. Such rainfall could come from a 1% storm with approximately 6.5 inches of total 24-hour rainfall. For comparison, the 1% 24-hour storm within this area ranges from 4.2 inches at Santa Clara University to 7.7 inches at Dahl Ranch to 8.5 inches at Stevens Creek and as high as 13.82 inches at Saratoga Gap, which represents the top of the Santa Cruz Mountains. (Reference is made to the State Department of Water Resources Bulletin #195.) These are offered as supporting evidence that the 6.5 inches of average rainfall from a 1% storm over the Adobe, Barron, and Matadero Creeks watersheds is very realistic.

The final design flow (2369 cfs) adopted for the Matadero Creek gage location is close to a weighted value based on the results obtained from statistical analyses, the rainfall/runoff analyses and the application of the regional regression equations. Table 1 is a summary of the results of these three independent methods. It shows a very close agreement among the results as compared to the weighted average and, therefore, the results of the regional analysis were selected for use in designing the facility. The study included urban hydrology methods (discussed in Ref. 8) which were used to determine flood flows from the pervious and impervious parts of the developed urban areas within the Palo Alto Flood Basin watershed. This entailed an intensive study of storm drain systems and land uses in order to understand the effect of these urban features on the rate and timing of runoff.

TABLE 1

SUMMARY OF DISTRICT FLOW VALUES
MATADERO CREEK @ USGS #1660

	Method	1% Peak Flow c.f.s.	1%-24 Hr. Volume c.f.s.-24 Hr.	Equivalent Excess Rainfall Inches
1)	Statistical Analysis of Recorded Data	1945	-	-
2)	Statistical Analysis of Recorded and Reconstituted Data	2310	710	3.7
3)	Rainfall-Runoff	2091	909	4.5
4)	Regional Regression	2369	912	4.5
5)	Weighted (2&4)	2320	745	3.70

The Linsley, Kraeger Analysis

Continuous Simulation

The City of Palo Alto hired Linsley, Kraeger Associates (LKA), a Palo Alto engineering firm, to derive an independent estimate of the design water surface elevation for the Palo Alto Flood Basin.

LKA used the Stanford Watershed Model (SWM), a deterministic approach. Rather than attempt to find the water surface in the basin resulting from the 1% flood, they derived what they describe as the "1% water surface elevation". The 1% flood refers to an amount of runoff with a 1% probability of occurring while the 1% water surface elevation refers to a basin water surface elevation with a 1% probability of occurring.

Using published records plus other rainfall records found at the local library and in their files, LKA arrived at a relationship between rainfall and runoff for the basin and developed a continuous series of runoff events. Following are the stated assumptions:

1. All culverts and bridges will be improved so that they offer no obstruction to flow.
2. All channels will be improved so that no overflow occurs upstream of Bayshore Highway.
3. No changes will be made in the existing tide gates in the flood basin.
4. No debris accumulations will be experienced at bridges and culverts.
5. There will be little further urban development.
6. Storm drains and pumping stations will remain unchanged.
7. No further subsidence will occur in the flood basin area.
8. No filling of Baylands will occur which might affect tidal levels.

The above are basic assumptions by comparison with the following more important, but unstated, assumptions that can lead to unacceptable results:

1. The assumed appropriateness of converting daily rainfall values into hourly values.

2. The use of average monthly evaporation rather than actual historical evaporation.
3. The assumed appropriateness of calibrating the Stanford Watershed Model over only a four-year period and generating 73 years of synthetic record.
4. The assumption that what is appropriate for design of the basin is the 1% water surface rather than the water surface resulting from the 1% flood. The Federal Emergency Management Agency (FEMA) would then be in a position of ruling on the appropriateness of each of the two recommendations (District's vs. that of LKA). Historically, FEMA has accepted the more conservative recommendations.
5. The assumption that the most important factor in the Stanford Watershed Model, K1, representing the distribution of rainfall over the watershed, was constant for all storms over the entire 73 years of record.

Unacceptable Results

The ways in which LKA adapted historical data to their Stanford Watershed Model are not acceptable for the following reasons:

1. Use of unpublished data found in the local library and in their own files.

   Rather than resorting to the use of unpublished rainfall data which can be unreliable, they could have used the published long-term record (more than 100 years) from the National Weather Service precipitation station in San Jose (Station # 86).

"No amount of unreliable data can be useful. In fact, unreliable data may lead to very erroneous conclusions. It might be better to have no data than information which is inaccurate and misleading.

Without provisions for assembly, checking and publication of data, a data program is incomplete. Checking for reliability should occur as soon after the data collection as possible. Publication should follow promptly so that the data are available to those who may wish to use them. Publication also provides insurance against loss or damage to original records". (Ray K. Linsley, "Symposium on Hydrometeorological Networks," Quebec, 1965).

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2. The choice of data which is a mixture of daily and hourly information from various locations.

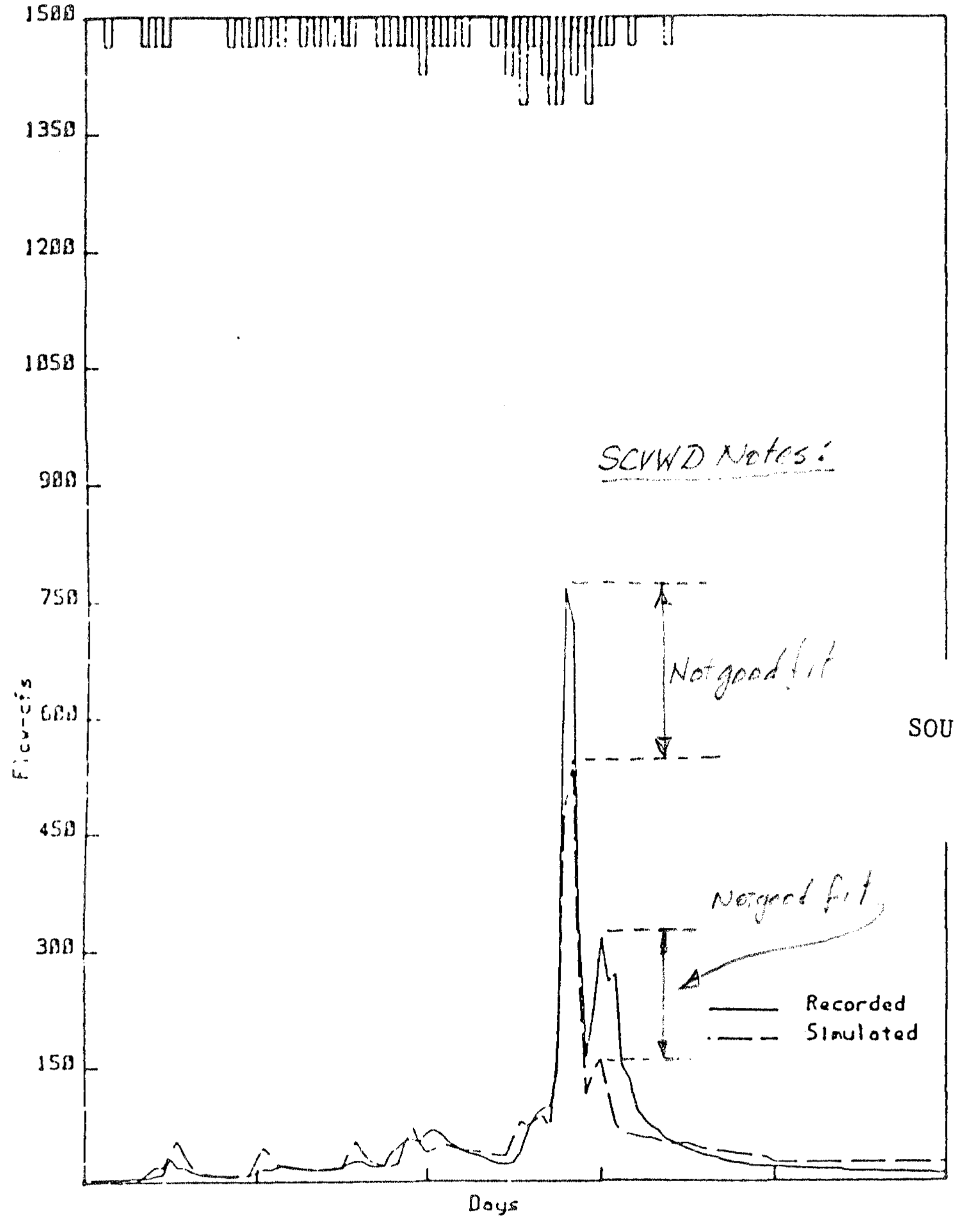
   Since the Stanford Watershed Model requires all the data to be in an hourly format, daily values were inappropriately converted (disaggregated) to hourly values. Doing this permits LKA to claim use of a longer history of hourly rainfall; however, the net effect of artificially converting daily totals of rainfall to hourly data without regard to actual rainfall intensities and their timing is to set the rainfall/runoff model up to produce results that are biased (that is, the results would be artificially low in this case). Peak events cause floods. Peaks are not reproducible from records of daily rainfall totals.

"As yet there is not an acceptable technique to disaggregate rainfall data and generate intensities of short durations (hourly) on stations with record of long durations (daily)." (Dr. John Schaake, former MIT professor, presently Chief of Hydrology Group, National Weather Service, telephone conversation, June 20, 1984).

3. Page 11 of LKA's report states that they used adjusted and disaggregated rainfall data with "no way to adjust timing and relative intensity". We believe it is a drawback of the simulation method that it is not possible to adjust synthetic data for the timing and relative intensity of actual historical events. LKA's claim that the model represents the actual behavior of past meteorological events is based on circumstantial data.

4. LKA's judgement of "good fit" of their graphed simulated data and the actual historical record is questionable:

   Page 22, Figure 7A of LKA's report, reproduced here is claimed to demonstrate good fit. In fact, no good fit can be seen. The peak flow rates differ by as much as 50%.



SCVWD Notes:

Not good fit

Not good fit

SOURCE: LKA'S, April, 1984 Report

Matadero.Cr.at.Palo.Alto

Fig. 7A Comparison of simulated and observed flood hydrographs, 2/5-9, 1983

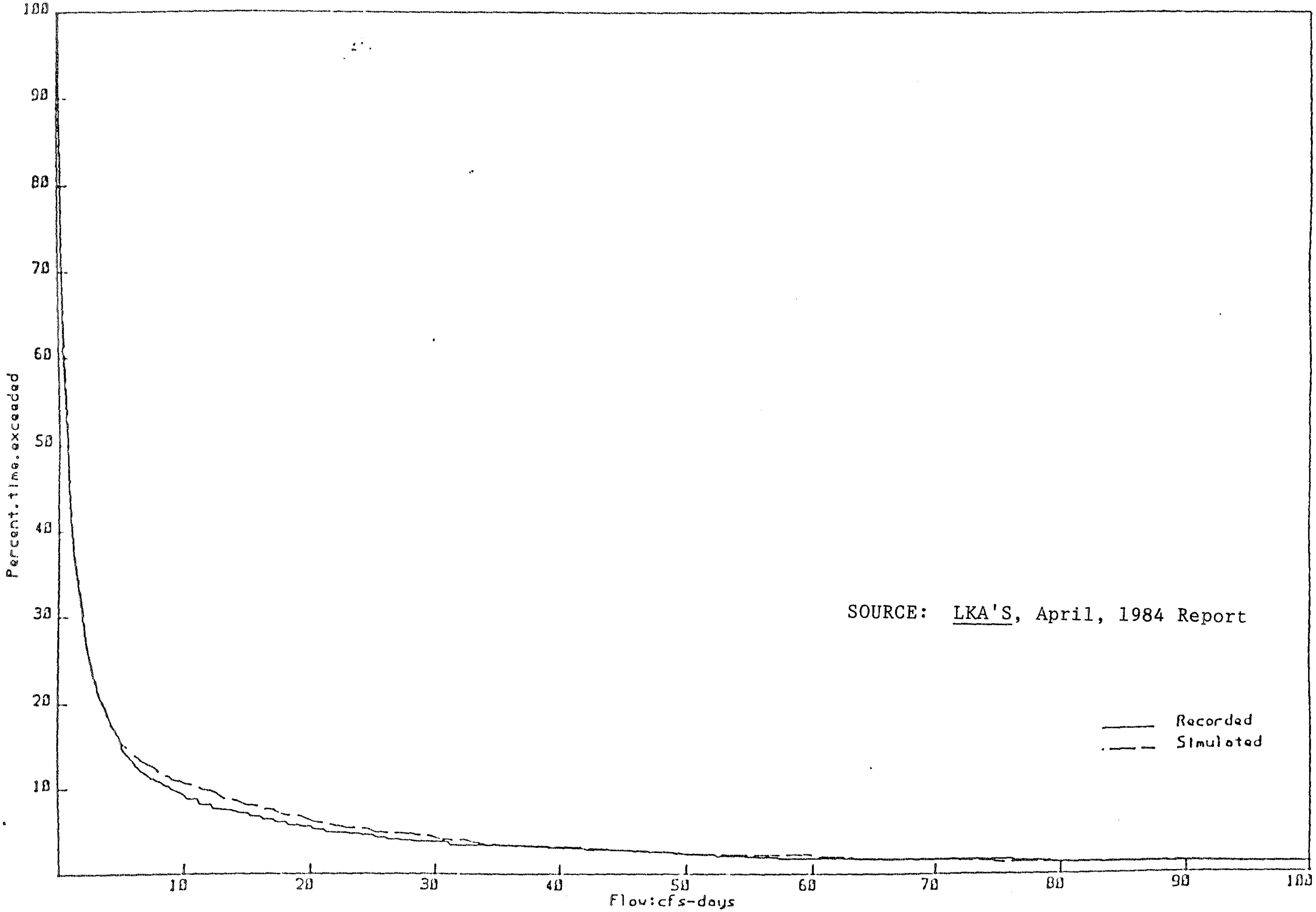
Pages 25 and 27, Figures 8 and 9 of LKA's report, also reproduced here show comparisons of simulated versus historical data. Even though these graphs are intended to show a good fit, they do not account for timing. Instead, they merely represent an analysis of durations.

Page 28, Figure 10 of LKA's report, reproduced here, shows historical flood peaks at the Matadero Creek stream gage near El Camino Real compared with their simulated data for that same station. It appears that there are two serious discrepancies:

a. Urbanization (houses, streets, driveways, rooftops, etc.) usually has the effect of producing higher peak runoff than non-urbanized, or rural, watersheds. Nevertheless, LKA's simulated line lies completely lower than the observed data.

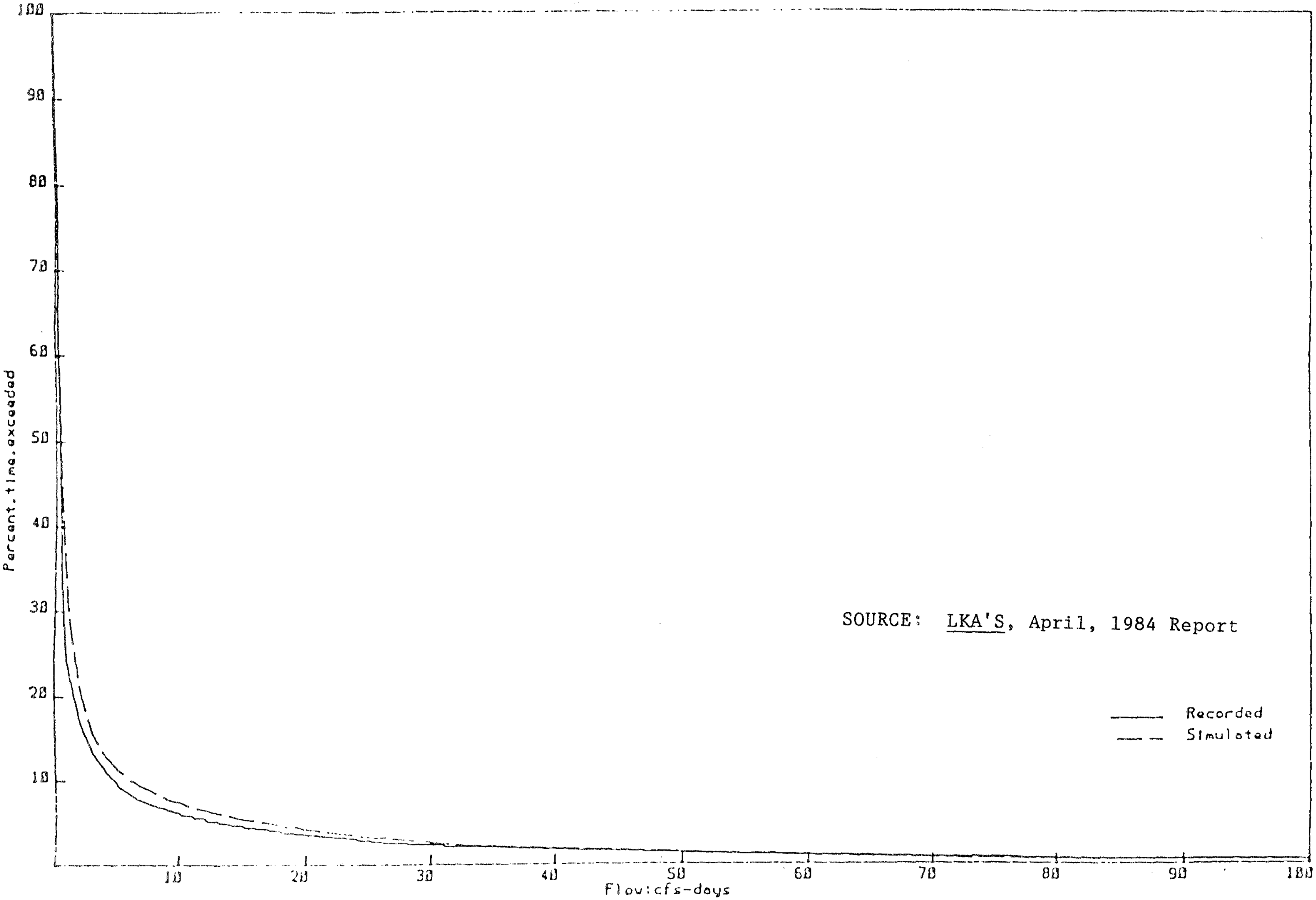
b. On LKA's Figure 10, based upon the historical record, the 1%, or 100-year, flood flow near El Camino Real is about 2,800 cfs for this 7.5 square mile section of the Matadero Creek watershed record. Nevertheless, LKA suggest that the 1% flow for the same creek downstream at Bayshore Freeway (drainage area about 14 square miles) is only 2,130 cfs. We don't know why doubling the watershed area would reduce the magnitude of peak flows. We would expect the opposite results.

5. The graph of maximum 1-day volumes, Figure 11, page 29 of their report (reproduced here), has been described by Mr. Linsley as the "best fit he has ever seen". While this observation may be true, we see no good fit between the two plotted lines. The graph demonstrates how the Stanford Watershed Model biases its results. Infrequent floods (right end of the graph) are made artificially low compared with historical data, while frequent floods are made artifically high. Flood control design, which has as its goal the



SOURCE: LKA'S, April, 1984 Report

Fig. 8 Comparison of simulated and observed flood hydrographs, 10/1/79- 9/30/83
Matadero.Cr.at.Palo.Alto



SOURCE: LKA'S, April, 1984 Report

Fig. 9 Comparison of simulated and observed flow duration curves, 10/1/69-9/30/83
Matadero.Cr.at.Palo.Alto

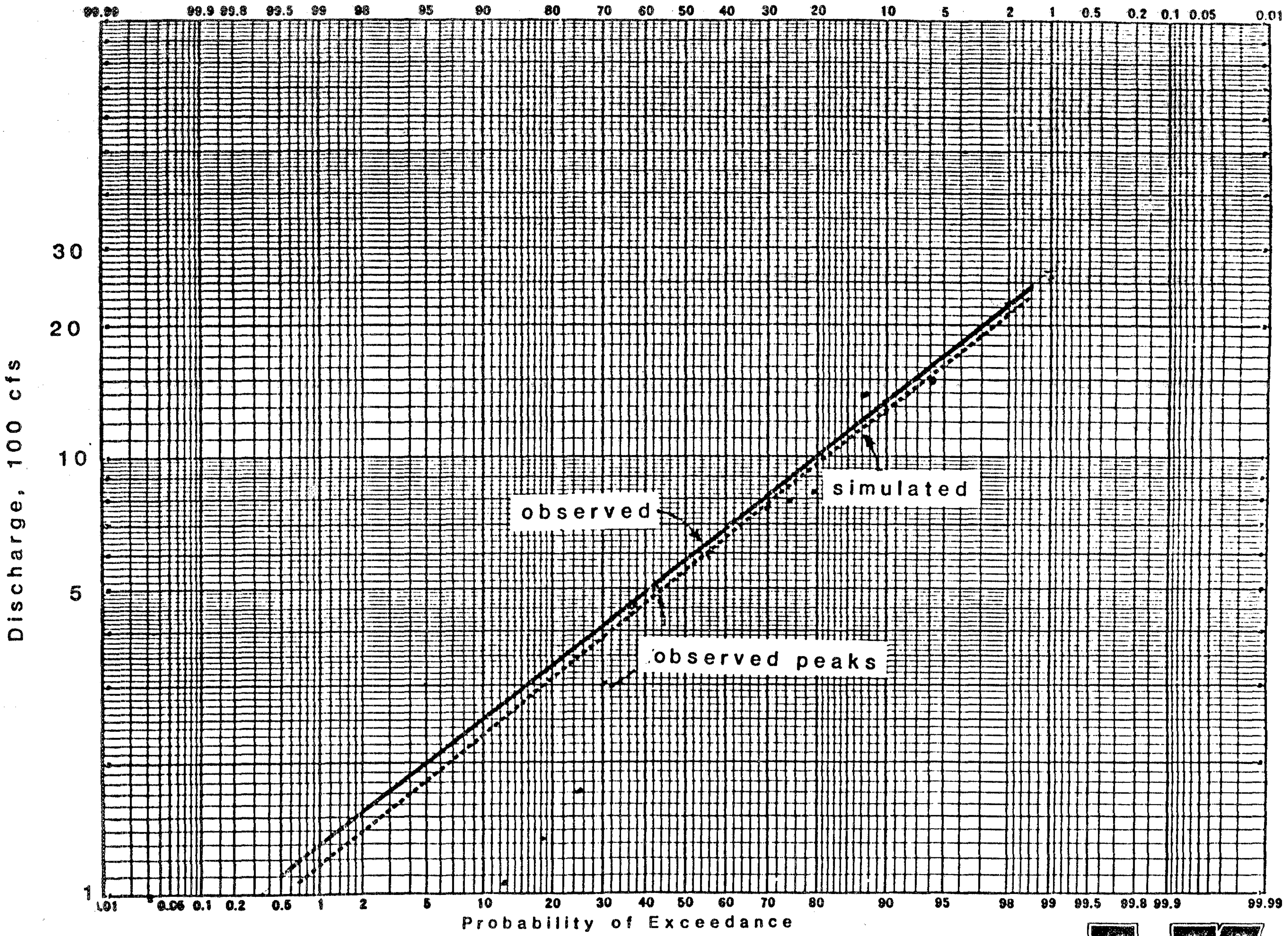


Fig. 10 Comparison of oberved and simulated flood peak frequency, Matadero Cr. near El Camino, 1969-83

Linsley, Kraeger Associates

the protection of lives and property, cannot rely on such a design technique that produces artificially low design peaks and volumes for the less frequent but more damaging floods.

6. Figure 11, page 29 of LKA's report, reproduced here, shows another assumption that has the effect of lowering design results. Restricting their analysis to 1-day (that is, calendar day) flood volumes, rather than maximum volumes in any 24-hour period (sometimes quite different and much more critical), has the effect of dampening, again, the projected results.

7. LKA's model was "calibrated" based upon only four-years of data (1979-1983) and, together with their synthetic rainfall data, the model was used to generate 73 years of continuous, hourly, streamflow data at all locations along Matadero, Adobe and Barron Creeks. LKA then assumed these simulated records to be random events — a theory that is very much debatable, especially with regard to extreme (flood) events.

8. LKA assumed that the distribution of rainfall over the watershed, represented by the ratio of yearly average rainfall values (K1), was constant for all storms during the entire 73 years of record. This is also an assumption that has the effect of dampening, or lowering, the magnitude of extreme flood events (such as the 1% flood). For example, for their subarea M1 (Upper Matadero Creek), their report states that the K1 factor is a constant value of 0.52 (Table 4, Pg. 32). In fact, for the January 1983 storm the K1 value computes (from actual records) to be 0.77, for the February 1983 storm, K1 computes to be 0.83 and for March 1983 K1 is 0.96. This factor, like everything else in nature, is not actually constant but varies with time and location. The assumption that the K1 value is constant may not be appropriate, especially for the generation of extreme events.

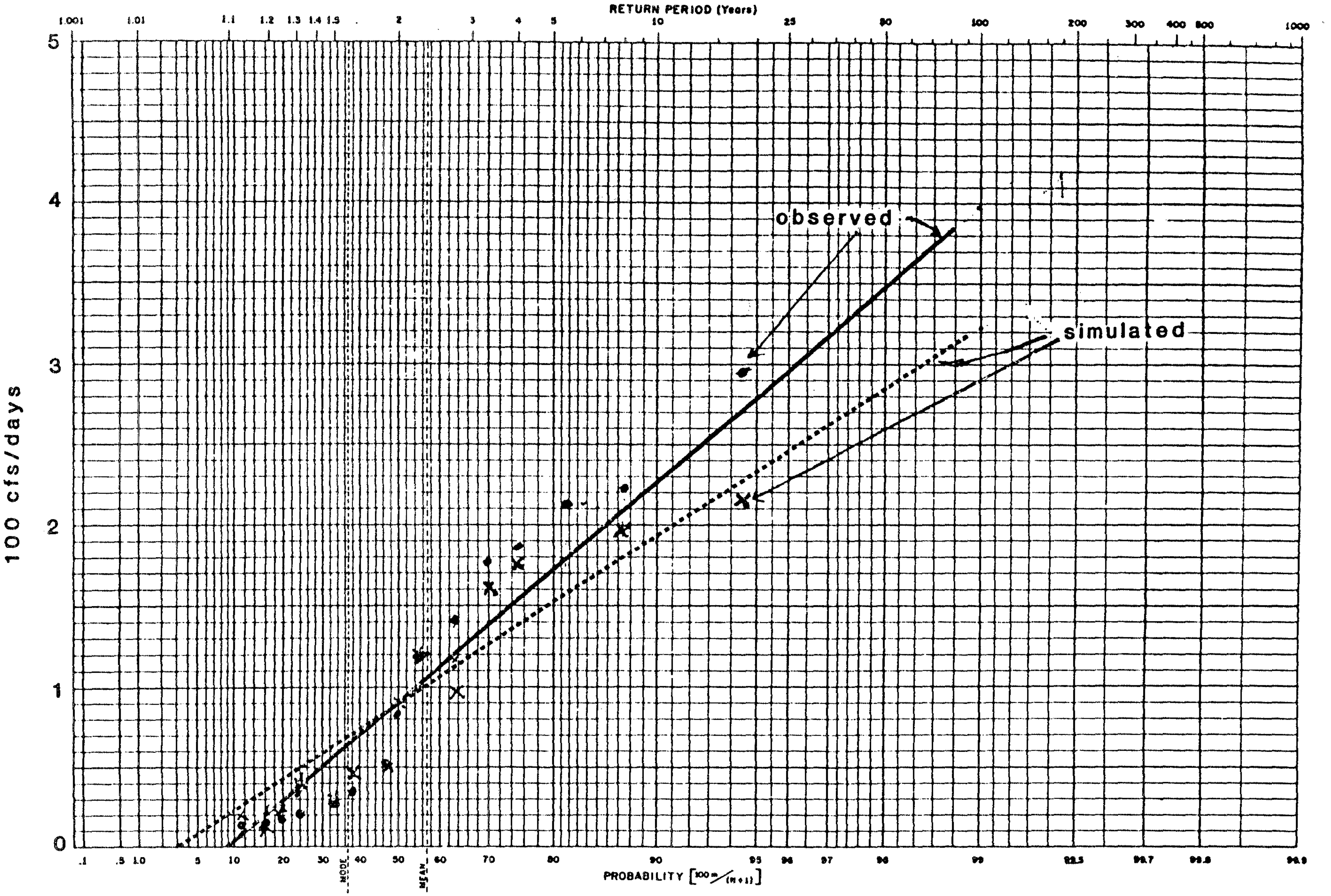


FIG. 11 Comparison of simulated and observed maximum 1-day flood volume frequency, Matadero Creek near El Camino, 1969-83

Linsley, Kraeger Associates

9. The flood of January 27, 1983 resulted in an estimated maximum water surface elevation in the Palo Alto Flood Basin of 3.0 feet (National Geodetic Vertical Datum, NGVD). This estimate was obtained by District survey crews surveying the high water mark as indicated in photographs taken 17 hours after the storm. It was later determined by the United States Geological Survey (USGS) that the flood on that date had a 20-year return period (17 years as calculated by the District). Linsley, Kraeger's estimate of the 100-year (1%) water surface elevation in the basin is 3.1 feet. The estimated high water elevation from January 1983 storm (3 feet) has been plotted by the District on LKA's Figure 13, page 36 and is reproduced on the following page. It demonstrates how the consultant's projection of water surface elevations appears to be underestimated.

10. The assumption that what is appropriate for design of the basin is the 1% water surface elevation rather than the water surface elevation obtained from the 1% flood is not acceptable, especially when all flood control projects in the area are based on the 1% flood.

Comparison of the Results of the Two Analyses

Table 2 compares the District's results with those of Linsley, Kraeger Associates. The table shows some disagreement in results - most significantly, the water surface elevation in the basin and the resulting recommended minimum elevation of the levee. The disagreement on the amount of encroachment any needed levee raising would have on the Baylands is very small, as shown on the table.

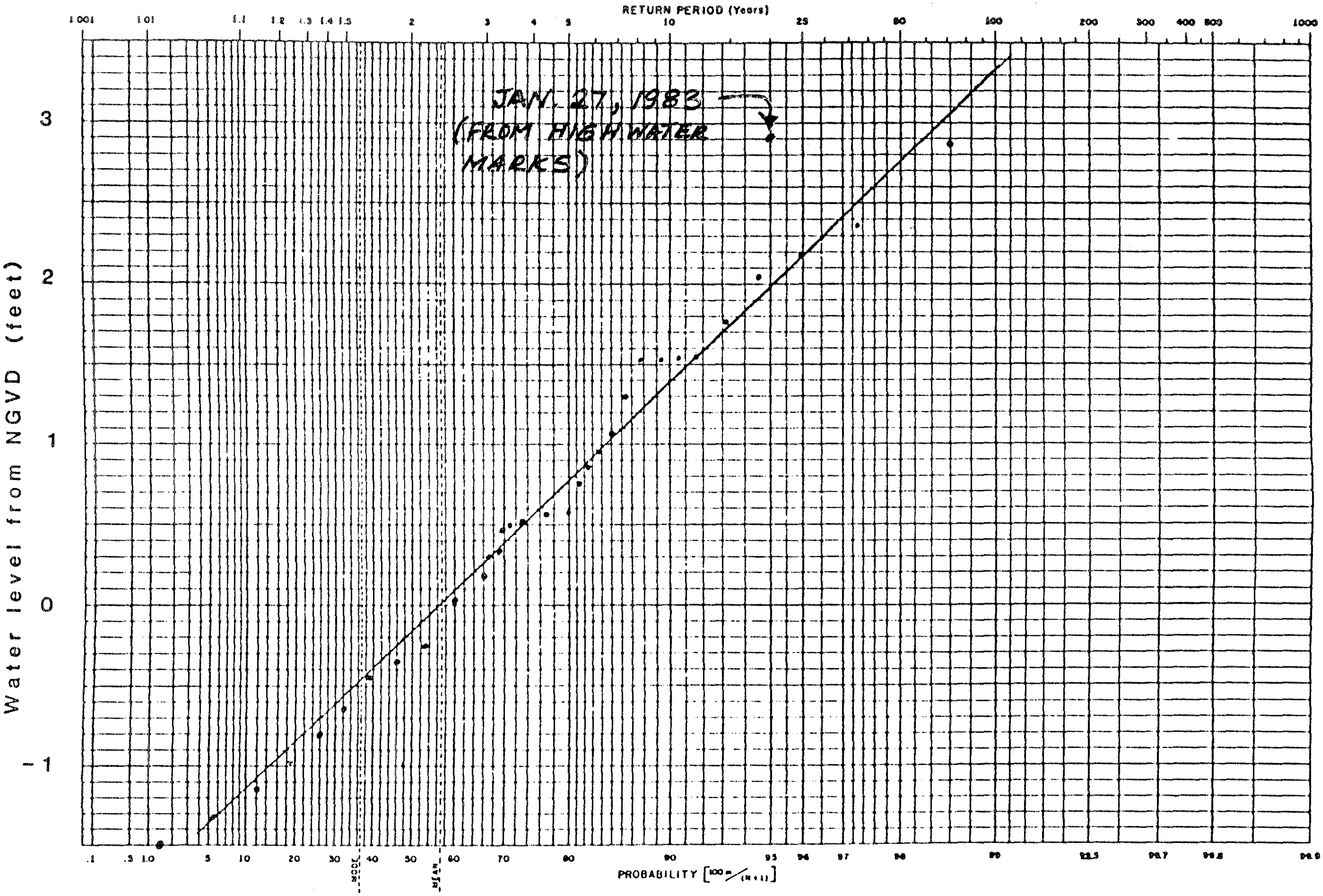


Fig. 13 Frequency of maximum annual water level in Palo Alto Flood Basin, 1910-83

TABLE 2

PALO ALTO FLOOD BASIN

Comparison of recommendations of Santa Clara Valley Water District and Linsley, Kraeger Associates (LKA).

	SCVWD	LKA
Water Surface Elev. from 1% flood	5.7'	-
1% water surface elevation	-	3.1'
Recommended freeboard	1.3'	1.0'*
Min. elevation of levee	7.0'	4.1'*
Direction of prevailing winds	from S/E	from S or S/W
Wind gage	Moffett Field	San Francisco Airport
1% inflow to basin		
Adobe Creek	3,080 cfs	2,178 cfs
Barron Creek	834 cfs	969 cfs
Matadero Creek	2,928 cfs (area = 14.0 sq. mi)	2,282 cfs
1% flow @ Matadero gage	2,360 cfs (area = 7.55 sq. mi)	2,800 cfs
1% Volume (24 hr.)	6,600 Ac. Ft.**	None provided
1% Flood basin volume	3,900 Ac. Ft.	2,600 Ac. Ft.
Encroachment on Baylands	0.4 Ac. net***	Minimal

* Linsley does not make a firm recommendation on freeboard or minimum elevation of top of levee. FEMA's freeboard criterion for such a case is 3.0 ft. unless a strong case can be made to FIA supporting less freeboard.

** The 6,600 Ac. Ft. volume of inflow to the basin is equal to 4.5" of average excess rainfall over the watershed.

*** 0.4 Ac. Net = 1.1 Acres of fill less 0.7 acres of new excavated wetlands. The design could be modified to result in a net increase in wetlands of about an acre.

WHY THE DISTRICT DOES NOT USE THE STANFORD WATERSHED MODEL

During the 1960's, when the District was developing its hydrologic methods, much work was done by the District using the Stanford Watershed Model. Under the direction of Ray K. Linsley (Carrol Bradberry and Associates), the model was used to simulate precipitation and streamflow data for some watersheds in the County.

After an initial period of testing it was decided to abandon the Stanford Watershed Model (simulation) approach and adopt the statistical hydrology method that is in use today.

Some of the reasons for abandoning the Stanford Watershed Model were:

1. The results were deemed unusable because they were inconsistent with data obtained from other reliable sources.
2. Some design flows resulting from the model were lower than recorded data.

The USGS research into the use of deterministic, continuous models that are similar to the Stanford Watershed Model indicates that these tend to produce dampened, or lowered, flows or volumes for the larger, less frequent (near the 1% flood) events, and exaggerated flows or volumes for the more frequent floods (Ref. 20, 21). Again, Linsley, Kraeger's Figure 11, referred to earlier in this report, illustrates these effects for the Palo Alto Flood Basin Study.*

Inventory of Stanford Watershed Model (SWM) Users

The Hydrology Committee of the Water Resources Council determined in their 1981 research that less than 1% of all agencies in the U. S. use deterministic modeling (Stanford Watershed Model "SWM" or similar models) in their flood control studies. Table 3 reproduces the results of that Water Resources Council study.

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* A recommendation of the panel of hydrologists - convened in 1976 to review the District's methods - to use simulation as additional information in the choice of design flows does not apply in this case because of the difference, among other things, in the basic objectives; the District's objective is to find the water surface elevation resulting from the 1% flood; LKA's objective is to find the 1% water surface elevation regardless of the flood.

TABLE 3

USE OF HYDROLOGIC PROCEDURES
(In Percent)

Procedures	Federal Agencies	State Highway	Private Sector	Total
Statistical, unit hydrograph (SCVD)	73	58	75	69
Empirical Equations	24	38	17	26
Simulation (Linsley, Kraeger)	0	0	1	less than 1%
Other	3	4	7	4

Adapted from Table III-2, U. S. Water Resources Council, Estimating Peak Flow Frequencies for Natural Ungaged Watersheds, 1981.

Our own investigation, summarized in Table 4 shows that none of the polled flood control agencies in California and elsewhere rely on the Stanford Watershed Model at the present time and there are no plans by them to use it for flood control design applications in the future. San Mateo County used the model at one time to determine the hydrology of the creeks draining the western slopes of the Santa Cruz Mountains. The results proved unsatisfactory near Highway 280 and were not used. As described above, in the late 1960's the Santa Clara County Flood Control and Water District used the technique in a contract with Carrol E. Bradberry & Associates, consulting engineers. The results were found to be inappropriate for flood control design (that is, they did not seem to fit with historical records) and were not used. In addition, Santa Barbara County used the SWM for flood forecasting and watershed management, but later abandoned it because of similar observations with regard to the SWM results compared to the historical record.

TABLE 4

HYDROLOGIC METHODS USED BY FLOOD CONTROL AGENCIES IN CALIFORNIA (APRIL 1984)

	Method	
Flood Control Agency	SCVWD or Similar	Stanford Watershed Model or Similar
Los Angeles County	Yes	No
Alameda County	Yes	No
Contra Costa County	Yes	No
Marin County	Yes	No
Monterey County	Yes	No
Riverside County	Yes	No
San Bernardino County	Yes	No
Santa Barbara County	Yes	No
Santa Clara Valley Water District (SCVWD)	Yes	No
San Diego County	Yes	No
San Mateo County	Yes	No
Soil Conservation Service	Yes	No
Corps of Engineers	Yes	No

Table 5 is a list of agencies and firms that are using SWM. It was obtained from Anderson-Nichols and Company, a Palo Alto engineering firm whose employee testified before the Palo Alto City Council on the evening of April 30, 1984 that many firms and agencies nationwide use SWM for flood control design. We have shown actual individual uses of the Stanford Watershed Model based on our telephone poll of these agencies taken in June 1984. (Two of the agencies on their list are located in Canada and were not called and the hydrologist of the third agency in Waukesha, Wisconsin, was unavailable for discussion). It is clear that a very limited number of agencies are using SWM for flood control design.

Some agencies have been trying to get the Flood Insurance Administration to accept, as a working principle for floodplain management, the concept of an Isorisk Line representing the water surface elevation of a certain frequency (Mike McJilton, Dupage County, Illinois). At present, the FIA considers the 100-year flood - - meaning the flood with a 1% chance of being equalled or exceeded in any given year - - as their working standard because "the adoption of such a standard helps to assure a degree of uniformity in (FIA) program guidelines". The FIA guidelines for the evaluation of a 1% flood "include such factors as flood area and depth, velocities and pressure, rates of rise and duration, etc., together with regionalized streamflow characteristics so that recorded data may be applied at ungaged sites" (A Unified National Program for Flood Plain Management, U. S. Water Resources Council, 1976). These guidelines also govern the District's methods and procedures. The Isorisk Line concept, as utilized in the Palo Alto study by Linsley, is based on a probabilistic water surface elevation that does not correspond to a specific flood peak, volume or any one of above-mentioned flood factors. It represents a completely different function that does not relate to the FIA guidelines. (For example, the above-mentioned flood characteristics such as durations and velocities are not readily calculable by the Isorisk Line method.)

TABLE 5

MAJOR USERS OF STANFORD WATERSHED MODEL (SWM)
(User List Provided by Anderson-Nichols & Co.)

	Use of SWM	
Agency/Firm	Storm Water Management	Flood Control Design
Macomb County MI. (Fred Barnes) (313) 469-5325	Yes (water quality studies)	No
Metro Washington Council of Governments Washington, D. C. (Mike Sullivan) (202) 223-6800	Yes (water quality studies)	No
Dept. of Planning & Community Dev. Seattle, Wash. (Ray Heller) (206) 587-4689	Yes (water quality and storm drain design pilot study)	No
Dupage County Illinois (Mike McJilton) (312) 682-7540	Yes (storm drain design pilot study)	Determine isorisk lines (FIA has not accepted the premise of isorisk lines)
Dames & Moore Bethesda, Md. (Tony Knepp) (301) 652-2215	Water Supply	"Not applicable to flood control"

For all of the above stated reasons, the District cannot adopt the Stanford Watershed Model as a design tool; nor have any other flood control agencies that we know of, although several have experimented with it as has this District.

CONCLUSIONS

The Linsley, Kraeger study of the Palo Alto Flood Basin has produced an estimate of the 1% water surface elevation in the Palo Alto Flood Basin that is too low compared to recent storm experience and compared to long-term historical records of runoff volumes from the watershed of Matadero Creek. Their low results are caused by combining the following:

1. Inappropriate data sampling assumptions (Rainfall and runoff)
2. Inappropriate assumptions with regard to the spacial distribution of rainfall.
3. Modeling inaccuracies within the Stanford Watershed Model itself which attempts to simulate the continuous rainfall/runoff relationship.

Because the Stanford Watershed Model relies heavily upon rainfall records, and because the resultant simulated flows are much less representative of watershed response than streamflow records, the design values are made unacceptably low in this study. Figure 4 shows a direct comparison of historical volumes against those developed by the Water District and by LKA. The results of LKA's study are notably low when compared with the historical record as shown on that Figure.

Table 2 of this report shows the comparison of the results of the two analyses of the Palo Alto Flood Basin. The major difference is the recommended elevation of the 1% water surface in the basin and, consequently, the recommended minimum safe elevation of the top of the basin levee.

The District believes that public safety will best be served by designing the basin to accommodate (with appropriate freeboard) a water surface elevation of 5.7 (NGVD), as borne out by the District's use of standard methods held valid by the vast majority of the flood control engineering profession.

APPENDIX I

Palo Alto letter to District of June 19, 1984

SANTA CLARA
VALLEY WATER DISTRICT

JTO
6/21

'84 JUN 21 AM 11:44

City of Palo Alto

CALIFORNIA
94301

OFFICE OF CITY MANAGER

(415)329-2563

P. O. Box 10250
Palo Alto, CA 94303

June 19, 1984

Mr. John T. O'Halloran
General Manager
Santa Clara Valley Water District
5750 Almaden Expressway
San Jose, California 95118

Dear John:

At its regular meeting of April 30, 1984 the Palo Alto City Council instructed the City staff to work with Linsley, Kraeger Associates and the Santa Clara Valley Water District with regard to the flood control project in the Palo Alto Baylands. The Council's motion directed us to:

a) reconcile differences between the District and the consultant; and

b) if the differences cannot be reconciled, then we are to clarify the disagreement between the consultant's report and the the SCVWD recommendations.

In either event, we are instructed to return the matter to the City Council within a reasonable time.

I gather from discussions held subsequent to the Council meeting that reconciliation of the differing points of view may be very difficult, if not impossible. If that proves to be the case, then I propose to concentrate on the last half of our assignment and attempt to pin down precisely where the two opinions differ.

In the conversations we have had, I have been impressed with the sincerity and responsibility demonstrated by you and your staff. I know that the District Board views its legal and public responsibilities for flood control with seriousness. Please be assured that the City staff is committed to finding a solution to this issue and that we intend to work with all parties to that end.

In order to get this project moving, I have asked Dave Adams to contact you directly.

Very truly yours,

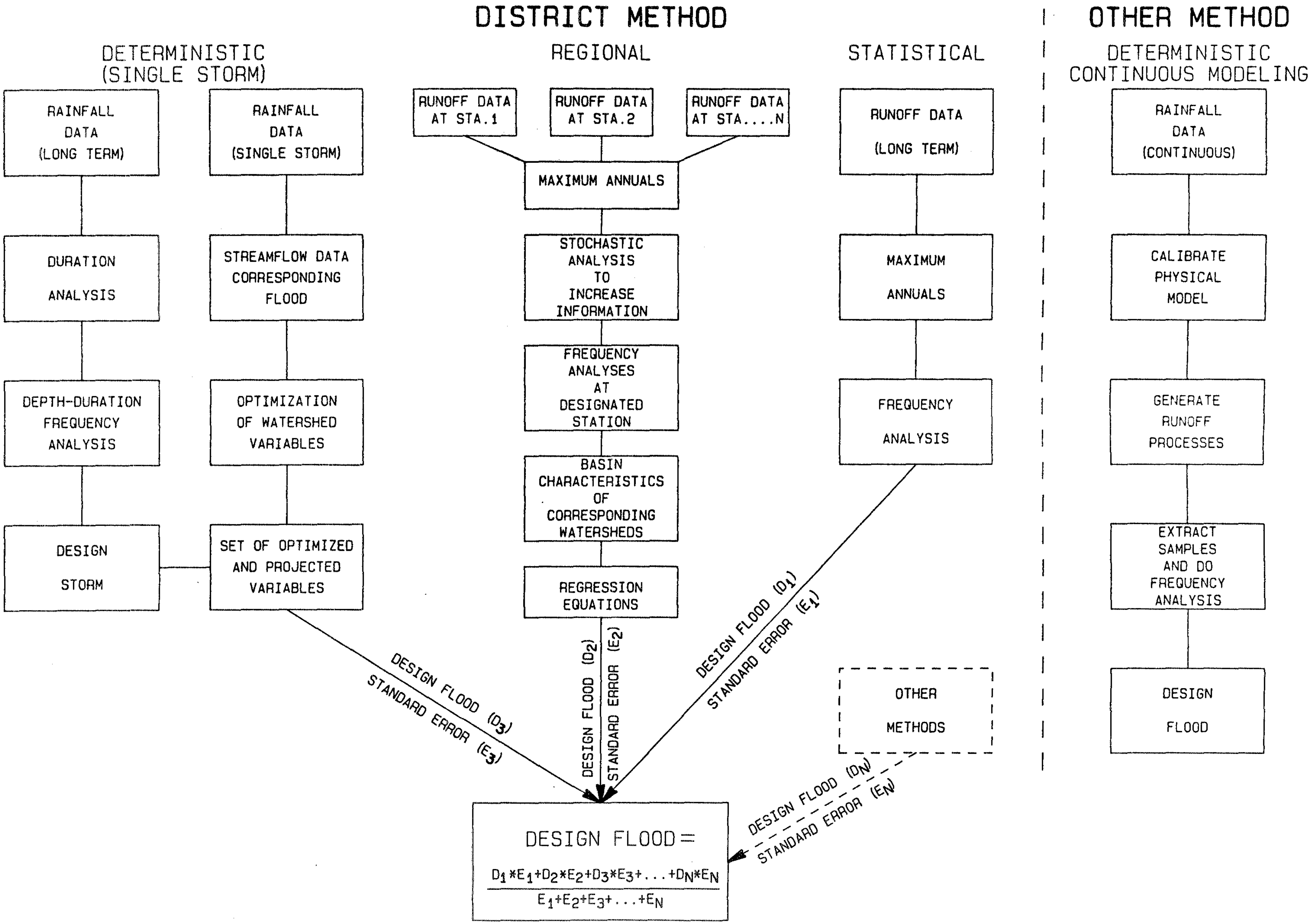
WILLIAM ZANER
City Manager

WZ/cf

cc: Dave Adams

APPENDIX II

Diagram of District's Hydrologic Method


DISTRICT METHOD
OTHER METHOD
DETERMINISTIC (SINGLE STORM)
REGIONAL
STATISTICAL
DETERMINISTIC CONTINUOUS MODELING
RAINFALL DATA (LONG TERM)
RAINFALL DATA (SINGLE STORM)
RUNOFF DATA AT STA.1
RUNOFF DATA AT STA.2
RUNOFF DATA AT STA....N
RUNOFF DATA (LONG TERM)
RAINFALL DATA (CONTINUOUS)
MAXIMUM ANNUALS
DURATION ANALYSIS
STREAMFLOW DATA CORRESPONDING FLOOD
STOCHASTIC ANALYSIS TO INCREASE INFORMATION
MAXIMUM ANNUALS
CALIBRATE PHYSICAL MODEL
DEPTH-DURATION FREQUENCY ANALYSIS
OPTIMIZATION OF WATERSHED VARIABLES
FREQUENCY ANALYSES AT DESIGNATED STATION
FREQUENCY ANALYSIS
GENERATE RUNOFF PROCESSES
BASIN CHARACTERISTICS OF CORRESPONDING WATERSHEDS
DESIGN STORM
SET OF OPTIMIZED AND PROJECTED VARIABLES
REGRESSION EQUATIONS
EXTRACT SAMPLES AND DO FREQUENCY ANALYSIS
OTHER METHODS
DESIGN FLOOD
DESIGN FLOOD (D3)
STANDARD ERROR (E3)
DESIGN FLOOD (D2)
STANDARD ERROR (E2)
DESIGN FLOOD (D1)
STANDARD ERROR (E1)
DESIGN FLOOD (DN)
STANDARD ERROR (EN)
DESIGN FLOOD =
D1*E1+D2*E2+D3*E3+...+DN*EN
E1+E2+E3+...+EN

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